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MULTIDISCIPLINARY RESEARCH OVERVIEW

(IHPTET/NPSS)

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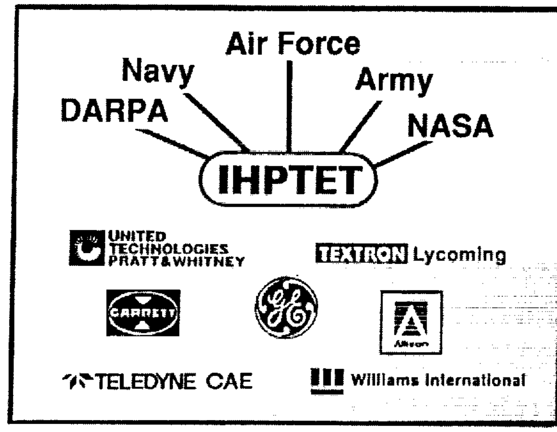
The Integrated High Performance Turbine Engine Technology (IHPTET) Program and the Numerical Propulsion System Simulation (NPSS) Program are two aeropropulsion multidisciplinary efforts at NASA Lewis that complement each other. The IHPTET initiative is an experimental program to advance engine development and double propulsion system capability by the turn of the century. NASA Lewis is contributing, with the Department of Defense and seven major aerospace contractors, to the development of these advanced, military, high-performance engines in the areas of compressors, combustors, turbines, nozzles, controls, mechanical systems, instrumentation, materials, structures, and computational fluid dynamics.

The NPSS effort is a computational, long-range program with the goal of reducing the cost and time of developing advanced-technology propulsion systems. This goal will be achieved through a cooperative effort of NASA, industry, universities, and other Government agencies to develop the necessary technologies for integrating disciplines, components, and high-performance computing into a user-friendly simulation environment. This simulation will allow for comprehensive evaluation of new concepts early in the design phase, before a commitment to hardware is made. It will also allow for rapid assessment of field-related problems, particularly where operational problems are encountered during conditions that are difficult to simulate experimentally. Data generated from the IHPTET engines will be used to help validate NPSS computations.

IHPTET Team



The IHPTET initiative represents a revolutionary new approach to engine development in which advanced materials, innovative structural designs, improved aerothermodynamics and advanced computational methods are synergistically combined to double propulsion system capability by the turn of the century.

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NASA Lewis is one of the team members involved in the Integrated High Performance Turbine Engine Technology (IHPTET) Program. The Department of Defense (DOD) and seven major aerospace contractors are also team members in this program to double turbine engine propulsion system capability by the turn of the century. NASA Lewis is contributing IHPTET-related research and technology to the program in terms of component research (i.e., compressors, combustors, turbines, mechanical systems, nozzles, and controls) and critical disciplines (e.g., materials, structures, instrumentation, and computational fluid dynamics).

NASA's IHPTET-Related R&T

- Emphasis on long-term, fundamental R&T
  - Strengthens fundamental knowledge base for IHPTET
  - Affects later phases of IHPTET
- Significant effort in numerical modeling of propulsion aerothermodynamics, structures, controls, etc.
  - Validated codes for analysis and design components
  - High potential for integrated disciplines
- Significant effort in advanced composite materials
  - Emphasis on improved fibers, processing methods, and design and life-prediction methods

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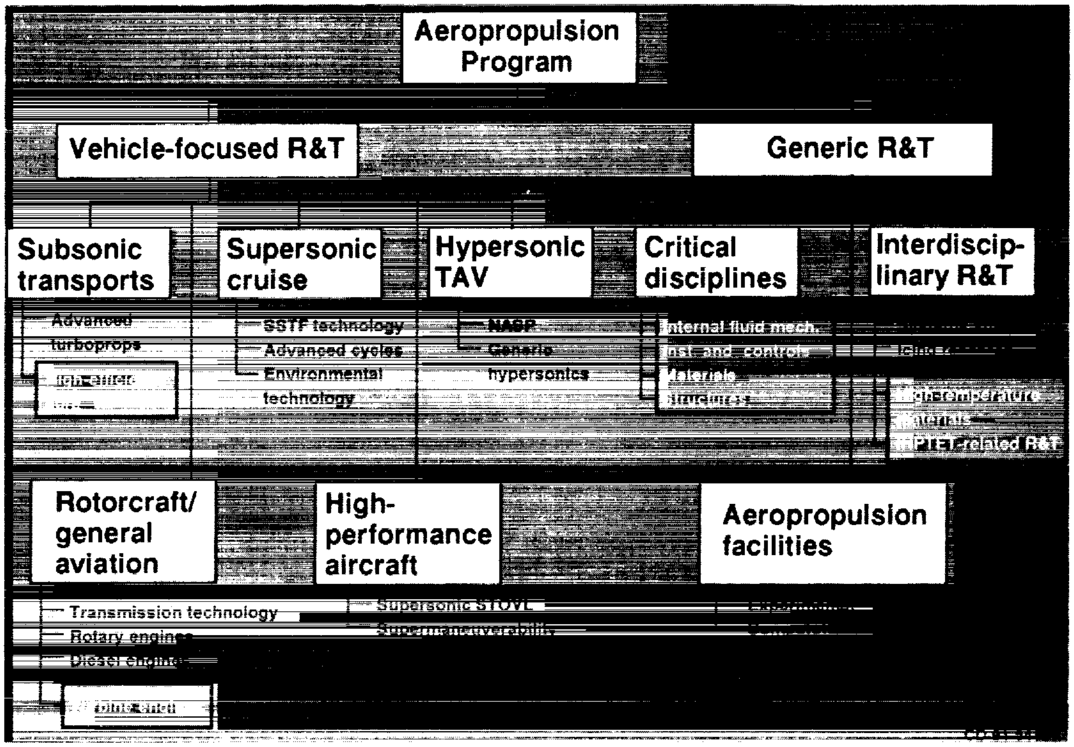
NASA Lewis' contributions to the IHPTET program are long-term, fundamental research and technology. Lewis' research efforts explore and strengthen the knowledge base of the IHPTET program. Results of this research will affect the later phases of the IHPTET program.

Lewis has a significant effort in the numerical modeling of propulsion aerothermodynamics, structures, controls, etc. Lewis leads the computational fluid dynamics effort in the IHPTET program.

The advanced composite materials effort at Lewis is contributing to the IHPTET program through the Lewis HITEMP program. Intermetallic matrix composites and ceramic matrix composites are being researched, and the results are incorporated into the IHPTET program. Polymer matrix composites are also being researched within the controls and diagnostics team for improved fibers and processing methods.

NASA Lewis IHPTET-Related R&T
Represented by Highlighted Blocks



The IHPTET-related areas of research in the NASA Lewis Aeropropulsion Program are highlighted in this figure. Under vehicle-focused R&T, IHPTET-related research is found in subsonic transports and rotorcraft/general aviation. Under generic R&T, IHPTET-related research is in critical disciplines and interdisciplinary R&T.

IHPTET-Related R&T Planning Team

NASA team members
Team leader: Susan M. Johnson, (216) 433–2163

	Area:	Lead:	Backup:
Components	Compressors	D. Miller (8352)	------------------
	Combustors	E. Mularz (5850)	R. Niedzwiecki (3407)
	Turbines	R. Roelke (3403)	K. Civinskas (5890)
	Nozzles	B. Blaha (3933)	E. Meleason (2164)
	Controls and diagnostics	G. Seng (3732)	R. Baumbick (3735)
	Mechanical systems	A. Kascak (6024)	E. Zaretsky (3241)
Disciplines	Instrumentation	D. Lesco (3728)	D. Williams (3725)
	Materials	B. Quigley (8672)	J. Stephens (3195)
	Structures	R. Johns (3253)	G. Halford (3265)
	CFD	R. Simoneau (5883)	R. Gaugler (5882)
	Air Force coordination	D. Stockert (6191)	------------------
	Army coordination	R. Bill (3694)	------------------

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This figure presents the NASA Lewis team members for IHPTET-related research. Each member is a focal point in her or his component or discipline area. Team members' telephone numbers, without the (216) 433- prefix, are given after their names.

NPSS Goal

- Reduce life-cycle costs by advancing system analysis capability through high-fidelity computational simulations by
  - Higher level of concurrent engineering
  - Rapid evaluation of effects of new and novel concepts on system performance
  - Early risk assessment
  - Early operability studies
  - Rapid evaluation of field problems
  - Assessment of performance degradation

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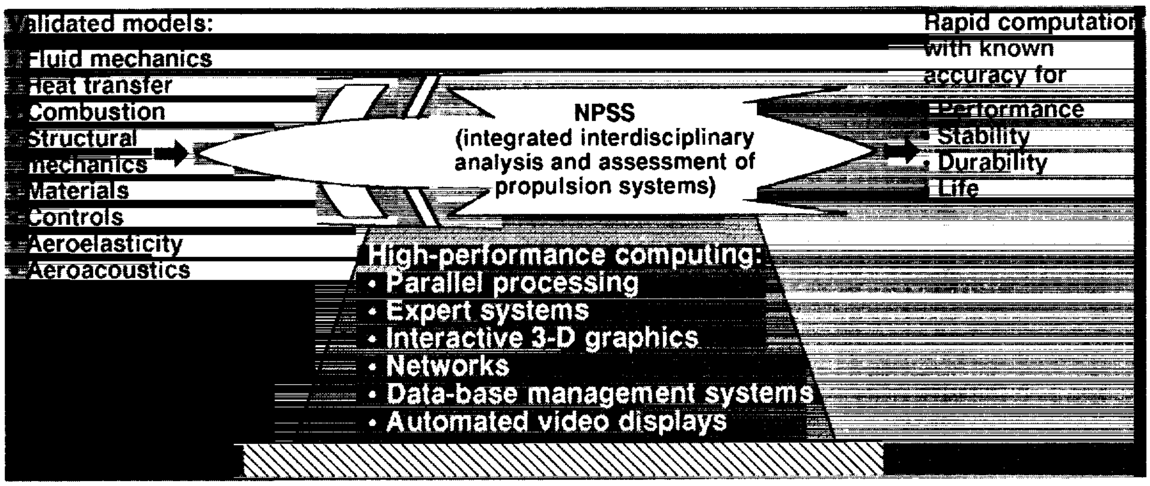
Implementing new technology in aerospace propulsion systems is becoming prohibitively expensive. One of the major contributors to the high cost is the need to perform many large-scale system tests. Extensive testing is used to capture the complex interactions among the multiple disciplines and the multiple components inherent in complex systems. The objective of the Numerical Propulsion System Simulation (NPSS) Program is to provide insight into these complex interactions through computational simulations. The tremendous progress taking place in computational engineering and the rapid increase in computing power expected through parallel processing make this concept feasible within the near future. However, it is critical that the framework for such simulations be put in place now to serve as a focal point for the continued developments in computational engineering and computing hardware and software. The NPSS concept will provide that framework.

NPSS—A Numerical Test Cell for Aerospace Propulsion Systems



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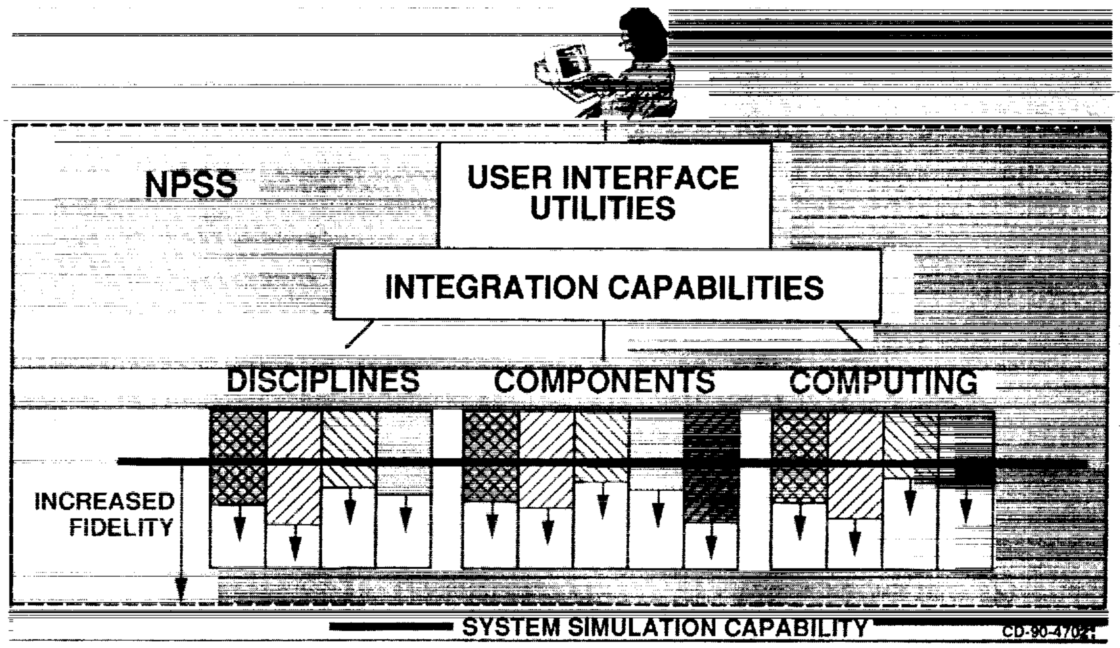
NPSS is a top-down systems approach that will provide designers with a tool to incorporate the relevant factors which affect system performance early in the design and analysis process when changes or modifications can be made relatively inexpensively. In terms of a propulsion system, such as an air-breathing gas turbine engine, this means coupling disciplines and components computationally to determine system attributes such as performance, reliability, stability, and life. Since these system attributes have traditionally been obtained in the test cell, NPSS is referred to as a "numerical test cell." A complete system analysis that includes multiple disciplines is a computationally intensive task. It requires a high-performance computing platform including both parallel and massively (i.e., more than 1000) parallel processors and a user interface that consists of expert systems, data-base management systems, and visualization tools.

The integrated, interdisciplinary system analysis requires advancements in the following technologies: (1) interdisciplinary analysis to couple the relevant disciplines such as aerodynamics, structures, heat transfer, chemistry, materials, and controls; (2) integrated system analysis to couple subsystems, components, and subcomponents at an appropriate level of detail; (3) a high-performance computing platform composed of a variety of architectures, including massively parallel processors, to provide the required computing speed and memory; and (4) a simulation environment that provides a user-friendly interface between the analyst and the multitude of complex codes and computing systems that will be required to perform the simulations.

NUMERICAL PROPULSION SYSTEM SIMULATION INTEGRATION



The implementation and integration of these technologies is a major challenge. The simulation environment and integration capabilities are depicted here. The system simulation is represented by the horizontal bar to signify that NPSS integrates into a system simulation the advancements that will continue to take place in the single-discipline, component, and computing fields. In this way NPSS will provide a focus for research and development in these fields. An additional challenge in NPSS will be the formation of interdisciplinary teams across NASA, industry, universities, and other Government agencies to develop and implement the needed technologies.

Estimated Computing Times for Interdisciplinary Propulsion Modeling, Analysis, and Optimization

Forced Response Prediction

Propulsion configuration being analyzed	Computing time, hr 100 MFLOPS	Computing time, hr 1 teraFLOPS
SSME turbine (linearized, unsteady aerodynamic model):		
1 Blade row (no optimization)	2	0.0002
4 Blade rows (full optimization)	10^3	.1
SSME turbine (Navier-Stokes aerodynamic model):		
4 Blade rows (full optimization)	10^6	100
Full engine* (full optimization):		
Navier-Stokes aerodynamic model	10^8	10^4
Modeled, filtered, and zoomed	10^4	1

*Includes 18 stages of turbomachinery.

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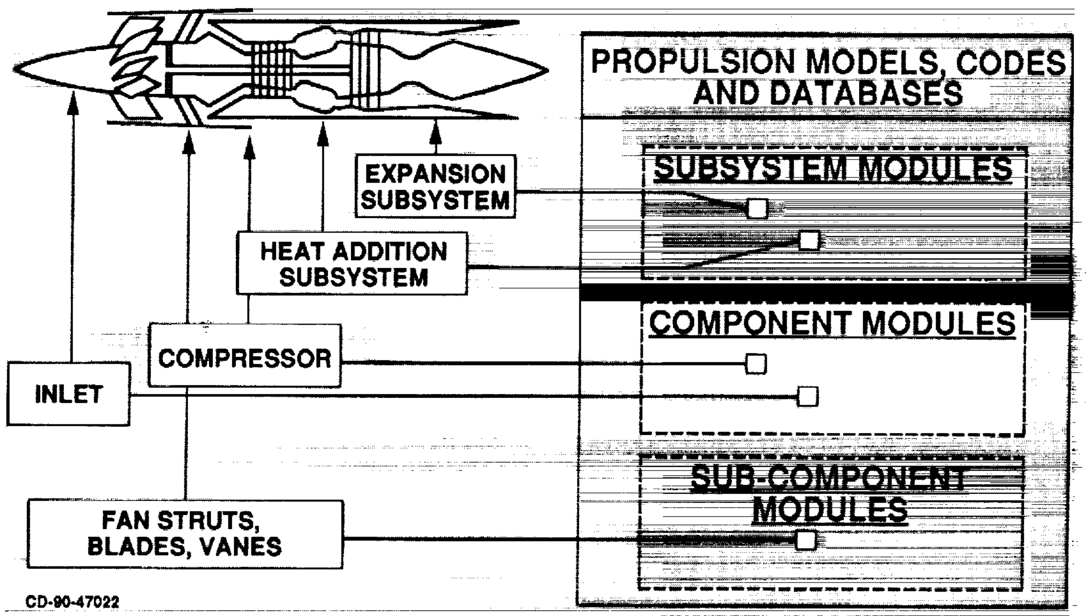
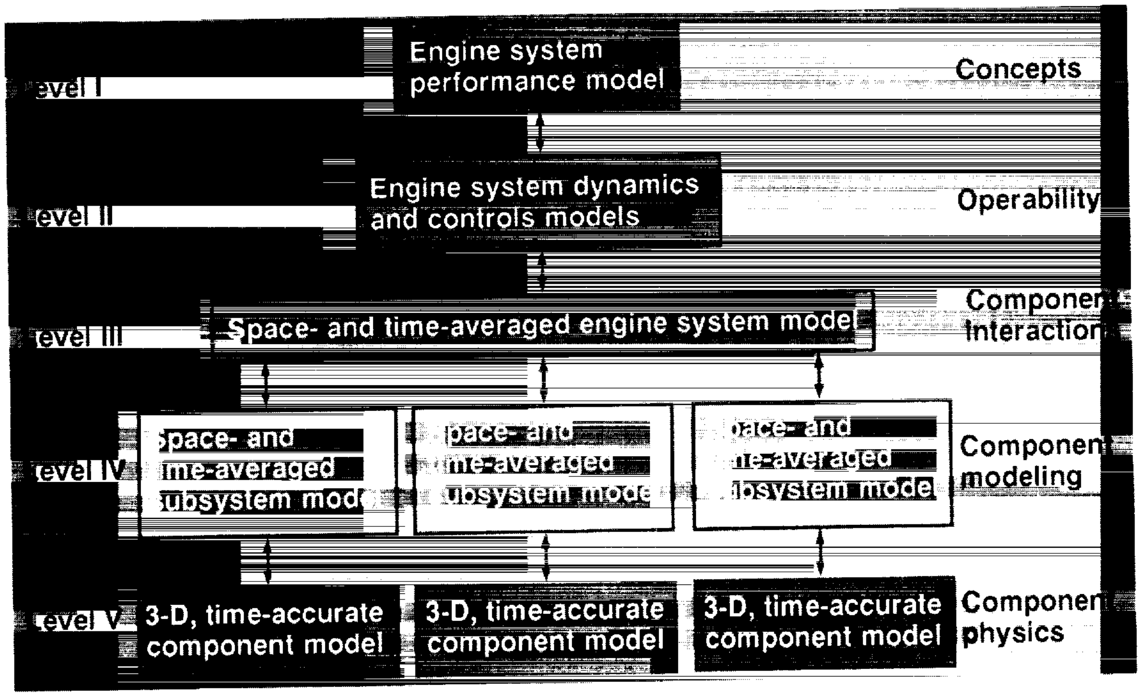
The computational system simulations will be based on the view that only phenomena that affect system attributes, such as the life, reliability, performance, and stability of a propulsion system, are of interest to the designer or analyst. In addition, detailed analyses of an entire propulsion system will be so complex that even computers of teraFLOPS (10^{12} floating-point operations per second) speed will not be sufficient to perform cost-effective computations.

NUMERICAL PROPULSION SYSTEM SIMULATION
"ZOOMING IN" ON FAN EFFECTS



Consequently, a framework is being developed that will allow the physical processes resolved from a detailed analysis of a component or subcomponent to be communicated to a system analysis performed at a lower level of detail for purposes of evaluating system attributes. Conversely, the system analysis will provide the ability to evaluate which physical processes, occurring on the component and subcomponent level, are important to system performance. This will allow the engineer or scientist to focus or "zoom in" on the relevant processes within components or subcomponents. The zooming concept is depicted here. In this particular example a detailed analysis of the fan would be performed to study, for example, the effect of a new blade design on system performance. The inlet and compressor would be modeled at slightly lower levels of fidelity to resolve phenomena such an inlet distortion or upstream influences of the compressor blading. The combustor, the turbine, and the nozzle would be modeled in less detail, perhaps to determine shaft horsepower and thrust.

Hierarchy of Interdisciplinary Simulation Models



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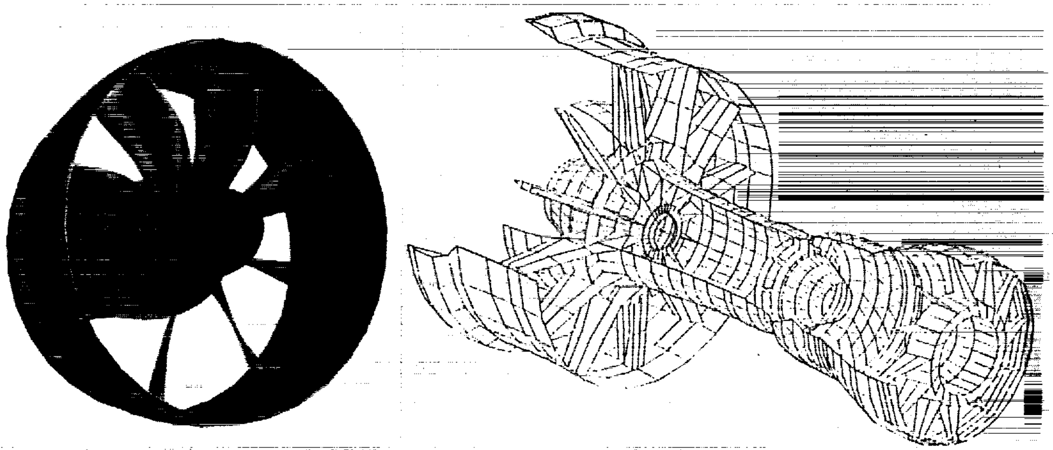
The implementation of the zooming approach requires a hierarchy of codes and models to be in place to provide a wide range of capabilities from detailed three-dimensional, transient analyses of components to time- and space-filtered analyses of the subsystems and systems. Modeling approaches will be developed for communicating information from a detailed analysis to a filtered analysis. Additional research will be required to understand the mechanisms by which phenomena on different length and time scales communicate. Research is already under way in computational fluid dynamics and structural mechanics to develop this modeling approach and will be extended to consider processes and scales appropriate for the entire propulsion system.

Single-Discipline Modeling



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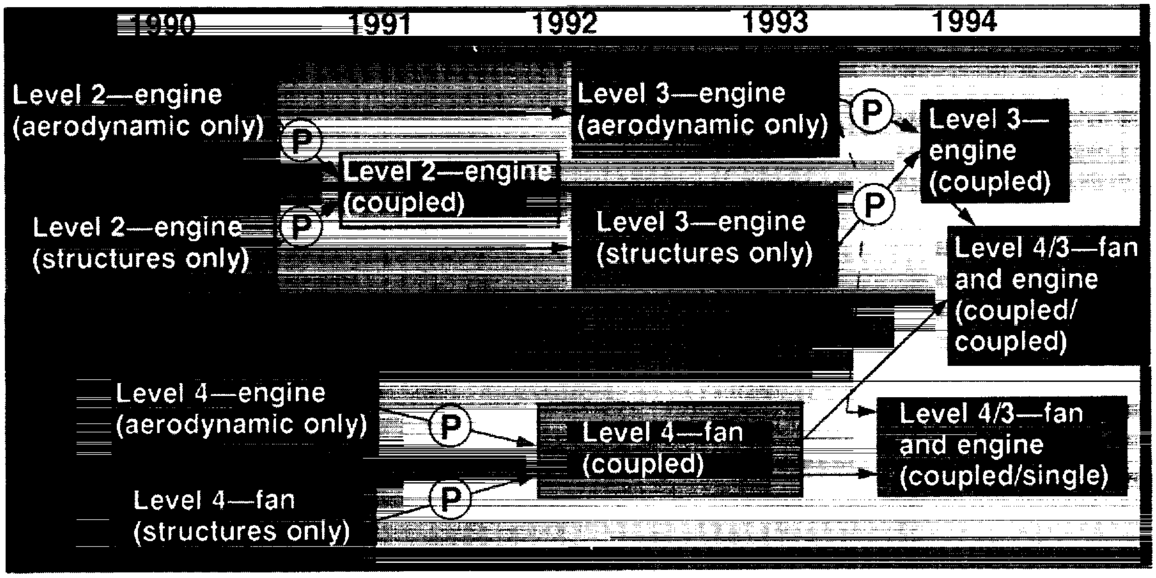
The fluid dynamic simulation model that will serve as the basis for the integrated system model will be the Adamczyk (ref. 1) average-passage formulation, which has been developed for multistage turbomachinery analysis. The average-passage model is based on the filtered forms of the Navier-Stokes and energy equations. This model was designed to resolve only the temporal and spatial scales that have a direct effect on the relevant physical processes. The effects of the unresolved scales, which appear as body forces and energy sources in the equations, are determined through semiempirical relations that are based on results from physical experiments or high-resolution numerical simulations. The results from the lower resolution analysis appear as boundary conditions for the high-resolution simulations. This model is currently applicable to time- and space-averaging of phenomena on the scale of the blade passing frequency and the passage size. Further development is required to extend the model for filtering in the presence of multiple scales and for other system components.

The structures modeling will be aimed at developing a comparable computational capability that will provide a means to traverse multiple scales of spatial resolution with a minimum number of variables at each level. In this way an analysis can proceed from a blade to a rotor to an engine core to the complete engine. The resulting system will have a minimum number of degrees of freedom consistent within the objectives of the analysis and will minimize the computational requirements. The methodology will be applicable to the solution of linear and incremental nonlinear analysis problems. This capability will be achieved through the formulation and implementation of a progressive substructuring technique.

NPSS Simulation Development Logic and Timing

Ⓟ Distribution or parallel implementation



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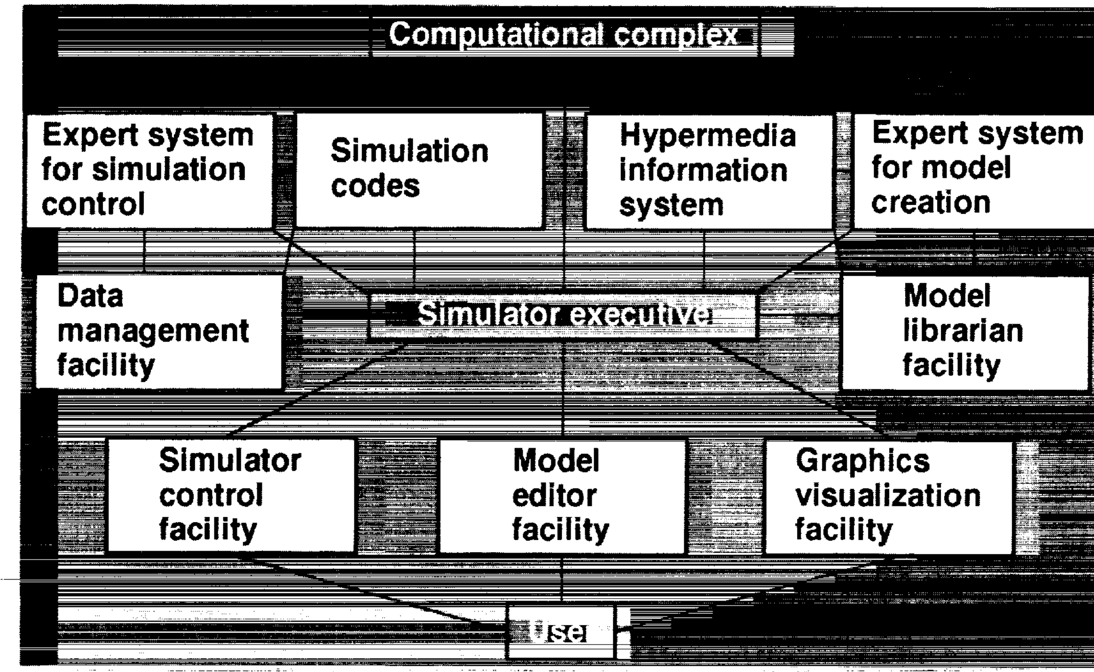
The Lewis NPSS Program is now developing a level 2 (one-dimensional, time accurate) system code by coupling a fluid mechanics code, DIG-TEM (DIGital Turbine Engine Model), and a structures code, TETRA (Turbine Engine TRansient Analysis). The first application of this simulation capability will be on the Energy Efficient Engine (EEE), which was built and tested by the General Electric Company under contract to Lewis. We will "zoom in" on the fan and provide a level 4 (three-dimensional, time accurate) simulation of the fluid mechanics, structures, and ultimately acoustics phenomena. This level 4 simulation will initially be used to provide fan performance maps for use in the level 2 system simulation. The resulting simulation will be compared with the data obtained from the EEE test. Once verification of this technique is obtained, the simulation will be used to change the engine fan geometry (e.g., move the flow splitters to change the bypass ratio), to analyze the transient stability of the fan (blade deflections can change the flow characteristics in the fan), and to perform tradeoffs between engine efficiency and acoustic emissions.

The development of appropriate level 5 simulations will require new physical models, new multidisciplinary coupling methods, and new computational techniques. Future efforts will be directed toward developing a level 3 two-dimensional (i.e., axisymmetric), time-accurate model of propulsion systems that will make up the backbone of the NPSS software.

Simulator Architecture



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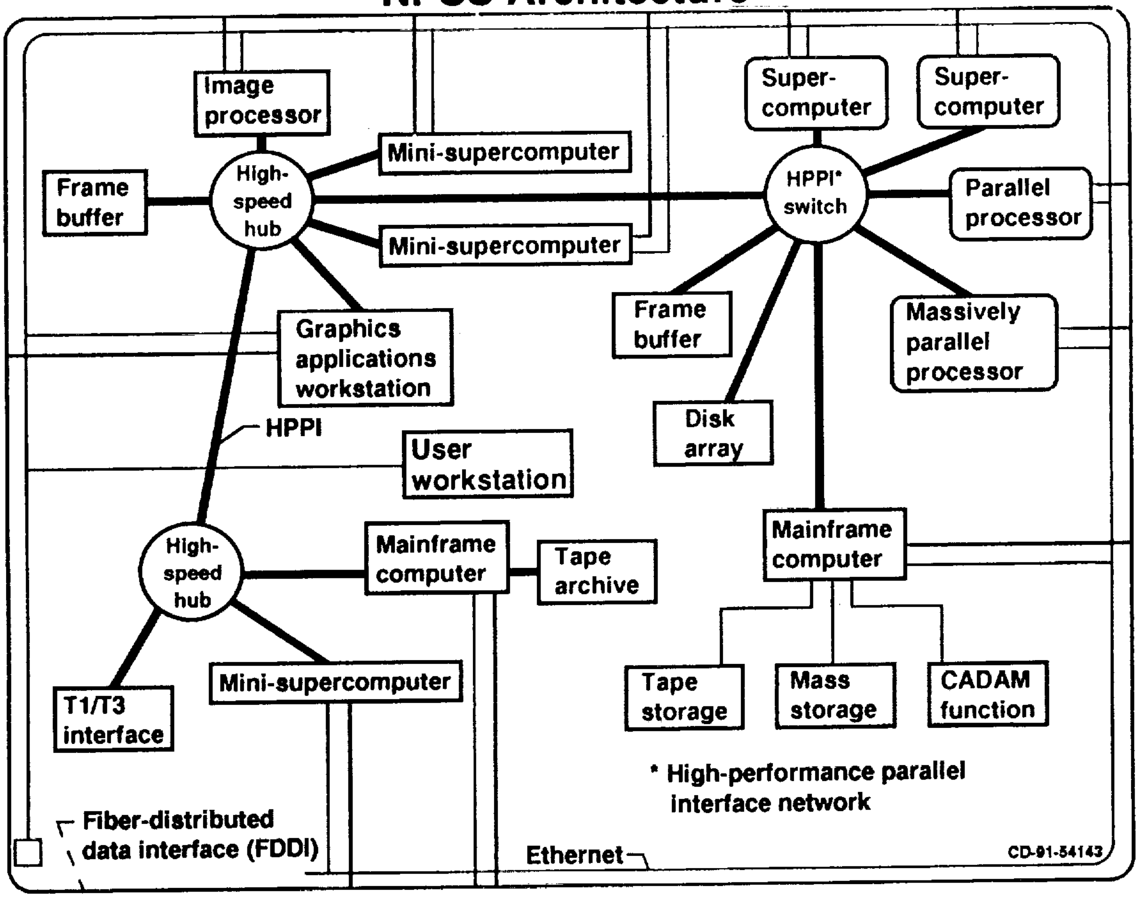
The capability for users to simulate, analyze, and optimize propulsion systems on high-performance, massively parallel computers will require extensive development of a user interface that will shield the user from the details of the computing system while providing sufficient guidance and assistance to perform the simulation at hand. The vision is that of a totally "seamless" environment. The environment consists of the integration of physical sciences, computer sciences, computer systems software, and computer systems hardware under the control of a global simulation executive. The computational simulation of multidiscipline, multicomponent problems entails a large number of variables that must be computed at multiple scales over multiple regions with results stored on local or global data-base environments. These types of problems can only be effectively solved by using massively parallel processors and networks where distributed parallel programming concepts can be readily implemented. Logic and software will be developed to adaptively allocate solution strategies and processors for a single discipline and for interdisciplinary analysis at both the local and global levels. Construction of simulations can be aided by a visual simulation editor coupled to an expert system "trained" in the use of the simulation codes. Artificial intelligence approaches, including expert systems and neural nets, will be investigated for assisting the user in making appropriate decisions in constructing a simulation. Advanced computer graphics, visualization, and animation complete this environment.

NPSS Architecture



It is expected that advances in parallel computing will make the integrated, interdisciplinary analysis of complex systems practical in design and analysis environments. At the same time it is expected that approaches to problem formulation and algorithm design will have to change to be able to exploit the new parallel architectures. Therefore, NPSS will establish a test-bed environment so that application and computer scientists can work closely together using state-of-the-art hardware and software tools to develop algorithms and to identify the appropriate computing architectures for propulsion system applications.

Computational Challenges in Propulsion Simulation

Nature of application	Critical computational technologies			
	Algorithms	User interfaces	Architecture	System software
Multiple disciplines	Tightly coupled; nonlinear	Visualization of multidisciplinary processes	Distributed heterogeneous	Large data bases; expert systems
Disparate scales	Hierarchical models; averaging/filtering; zooming	Visualization of multiscale processes	Reconfigurable; adaptive	Load-balancing; expert systems
Complex boundaries	Many-bodied real geometries	Interactive geometric modeling; grid generation	Reconfigurable; adaptive	Large data bases; load-balancing; expert systems
Engineering requirements	Robust, efficient, accurate, validated hierarchical models	Multipurpose tools; interfaces for simulation/analysis/CADAM	Distributed heterogeneous; teraFLOPS and beyond	Interactive portable tools; expert systems; compatibility

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The long-range goal of NPSS is to implement the shared-memory model, in either hardware or software, on massively parallel platforms. In the shared-memory model the programmer sees a uniform programming platform even though the hardware platform may consist of a variety of architectures such as cubes and rings. This not only simplifies the requirements for developing new code, but also provides the easiest, most flexible platform for the conversion of serial FORTRAN code, which proliferates throughout the computational engineering community today. The shared-memory model will allow this code to be used, without major revisions, for NPSS applications. Since the shared-memory model is a long-range objective, other technologies will be needed in the near term, including software tools for partitioning existing codes for solution on parallel computers.

Approach to NPSS

- Interdisciplinary analysis
- Propulsion system simulation at varying levels of detail (zooming)
- Uniform programming software standards
- Flexible, modular software architecture
- Propulsion system simulation on multiple available computing platforms
- Methodologies extended to massively parallel computational capability

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Products of NPSS Program

- Interdisciplinary models and algorithms for simulation and analysis of advanced propulsion system designs
- A simulation system architecture that integrates all of the required capabilities into a user-friendly computational environment
- High-performance computing technologies that enable rapid, interactive execution of the required algorithms and codes

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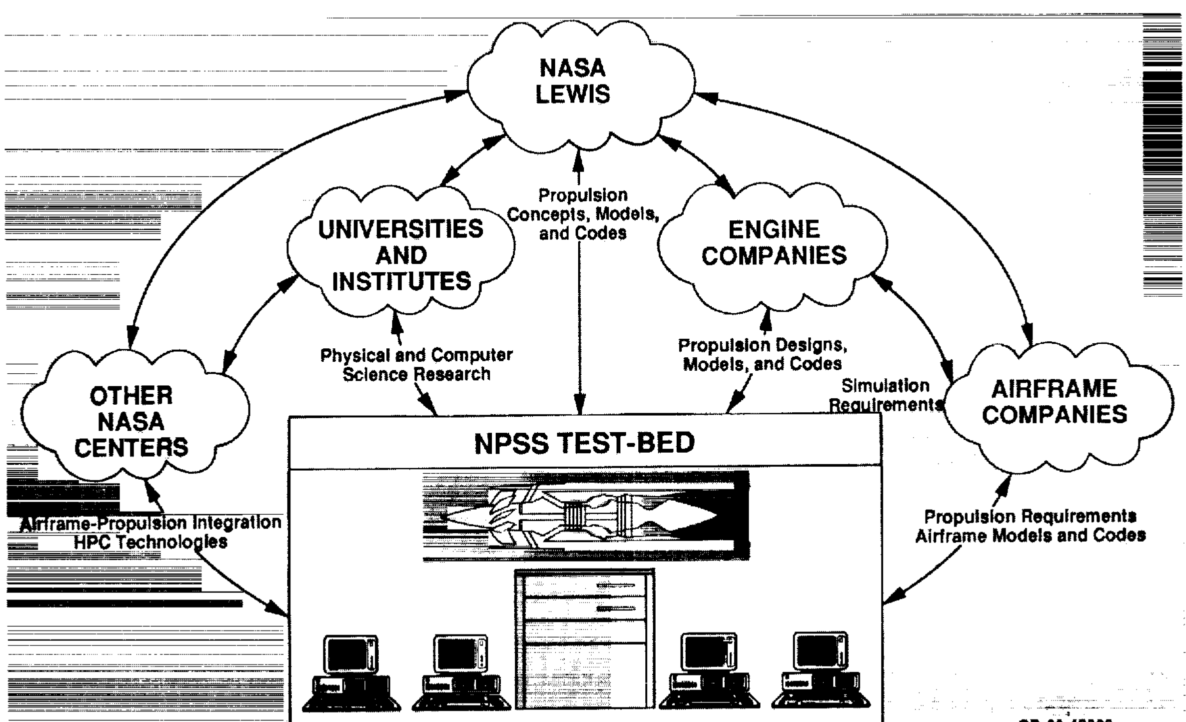
SUMMARY

The Numerical Propulsion System Simulation is a long-range program with the ultimate goal of reducing the cost and time of developing advanced-technology propulsion systems. This goal will be achieved through a cooperative effort of NASA, industry, universities, and other Government agencies to develop the necessary technologies for integrating disciplines, components, and high-performance computing into a user-friendly simulation environment. The technologies associated with the physical sciences must include model development that reflects an understanding of the relevant physical processes rather than brute-force computational analysis. The computational algorithms must be developed in concert with the computing architectures to ensure efficient performance, particularly with parallel and massively parallel processors. In addition, a strong and effective management team will be needed to form the interdisciplinary teams from all organizations that will be required to define, advocate, and implement these technologies. Therefore, the IHPTET Program, being an experimental and demonstration program, will be able to provide the NPSS Program with valuable turbine engine data for use in validating the codes and models.

THE NPSS PARTNERSHIP



REFERENCE

1. Adamczyk, J.J.: Model Equation for Simulating Flows in Multistage Turbomachinery. ASME 85-GT-226, 1985.